NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2716

EFFECT OF OPEN CIRCULAR HOLES ON TENSILE STRENGTH AND ELONGATION OF SHEET SPECIMENS OF A MAGNESIUM ALLOY

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Aluminum Company of America

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SUMMARY

The effect of open circular holes on the tensile strength and elongation of sheet specimens of magnesium alloy AM-C52S in both the annealed and the hard-rolled condition was investigated. Tests were made to study the effect of variable ratio of hole diameter to total specimen width and also the effect of spacing and arrangement of the holes.

It was found that greater reductions in strength were exhibited by the annealed material than by the hard-rolled material; conversely, the hard-rolled material showed the greater reductions in elongation. In general the results were similar to those of aluminum-base alloys (NACA TN 1974) except that the 1-inch-wide, single-hole specimen of the annealed material had a reduction in strength of about 19 percent compared with a maximum reduction of about 11 percent for any of the aluminum alloys tested.

INTRODUCTION

In the design of aircraft assemblies of aluminum- and magnesium-alloy sheet the effect of stress concentration at perforations such as rivet and bolt holes becomes important. The lightweight design of aircraft components demands small margins of safety to be used and this in turn requires suitable allowance in design for any strength reductions resulting from stress concentrations. An investigation (reference 1) of the type reported herein has been made on several aluminum alloys in sheet form and this report is an extension of that work to include a magnesium alloy.

The purpose of this investigation was to study the effect of open circular holes on the tensile strength and elongation of sheet specimens of magnesium alloy AM-C52S in both the annealed (AM-C52S-0) and the hard-rolled (AM-C52S-H) condition. Tests were made to study the effect of variable ratio of hole diameter to total specimen width and also the effect of spacing and arrangement of the holes. The evaluation of the effect of open circular holes on specimens such as those tested in this investigation will not be equivalent to that in the case of a riveted or bolted joint but will nevertheless serve to indicate the necessary precautions against such stress concentrations.

This work was done by the Aluminum Company of America and has been made available to the National Advisory Committee for Aeronautics for publication because of its general interest.

DESCRIPTION OF SPECIMENS

Descriptive dimensions of the various types of specimens are contained in table I. The specimen design used in the present investigation conforms to that previously used. All specimens were cut from 0.032-inch (nominal) sheet. Specimens were all 0.960 inch wide except for types 2 and 3 which were respectively 0.480 and 0.240 inch. All specimens were cut across grain. The holes were subdrilled with a No. 43 drill (0.089-in. diam.) and reamed with a No. 41 drill (0.096-in. diam.). These dimensions were arbitrarily chosen to give a ratio of hole diameter to sheet thickness of 3.

TESTING PROCEDURE

Dimensions of the specimens were accurately measured before testing. Width and thickness measurements were made with a micrometer caliper which was read to 0.0001 inch. Hole diameters were determined with plug gages. Average measured dimensions are listed in table II for each type of specimen. The maximum variation of any measurement from the average was less than 1 percent.

Net areas were obtained by multiplying the least net width by the thickness of the specimen. For specimens containing staggered holes, the net width was obtained by deducting from the gross width the sum of the diameters of all the holes in the chain and adding for each gage space in the chain the quantity,

$$\frac{s^2}{4g}$$

where

s longitudinal spacing (pitch) of any two successive holes (measured in the direction of stress), inches

g transverse spacing (gage) of the same two holes (measured normal to the direction of stress), inches

Nominal values of pitch and gage were used in calculating net areas.

All types of specimens were tested in triplicate. The tensile strengths determined for the solid specimens were averaged and the result was used as the tensile strength for the material. Specimens were tested in a 40,000-pound-capacity Amsler testing machine.[1]

Elongations on various gage lengths were measured on solid specimens and specimens containing a single central hole. These elongations were obtained by the use of the photogrid method, a 0.1-inch grid being printed on one surface of the specimen (reference 2). The changes in distance between adjacent lines in the grid were measured with a 42-power micrometer microscope. Readings were taken along the center line of the specimen. For the perforated specimens, the broken pieces were matched together and clamped in position. Measurement was then made of the gap at the edges of the hole and this distance subtracted from the measured distance between the nearest two transverse lines. The results, therefore, represent the elongation occurring on the longitudinal center line of the specimen.

RESULTS OF TESTS AND DISCUSSION

Tensile Properties of Materials

Mechanical properties are listed in table III along with typical values (reference 3). Average values are given for the tensile strength. The maximum variation from average was 1.5 percent. The mechanical properties determined are in good agreement with the typical values given for the materials.

Specimens with Single Central Hole

Specimens with a single central hole are those comprising series I in table I. These tests were made to study the effects of the ratio of

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[1] Type 20 ZBDA, Serial No. 4318.

hole diameter to total specimen width. Variations in this ratio were obtained by varying the width of specimens, the hole diameter and the thickness of material remaining constant. A summary of the results of the tests on this group of specimens is given in table IV. Values obtained from the A specimens (on which grids had been printed) were not used in obtaining the average results for this series of specimens. These specimens, tested at a later date and in a different testing machine, indicate results which are not consistent with the B and C specimens. This is particularly evident in the case of the type 3 specimen, where, because of the extremely small cross-sectional area, any inaccuracy in measurement would be of prime importance.

The efficiency values as a function of d/b (ratio of hole diameter to total width) are shown in figure 1. It may be seen that AM-C52S-O exhibits its minimum value of efficiency, equal to 81 percent, at approximately $d/b = 0.1$. Because of the small cross section of the sheet specimens tested in this investigation no attempt was made to measure reductions in area. It has been shown, however, (reference 4) that the percent reduction in area is a function of d/b and the value of d/b for minimum reduction in area agrees well with the value of d/b for minimum efficiency. Alloy AM-C52S-H seems to be practically insensitive to a change in the ratio d/b, having a nearly constant value of efficiency equal to about 96 percent.

Inspection of the specimens revealed considerable narrowing down of the specimen across the fractured section which would seem to indicate that if this pattern were repeated in a wide specimen less reduction in strength would occur.

Contradictory to what might ordinarily be expected, the annealed material exhibited greater reductions in strength than the hard-rolled material. The primary reason for this is not too clearly known although several partial explanations have been suggested (references 5 to 8). There does not seem to be any common index by which to predict the effect of the perforation on the strength reduction.

Figure 2 shows the elongation of standard tensile specimens over various gage lengths. These curves indicate the manner in which percent elongation decreased with an increase in gage length (reference 9). The effect of a single central hole on the elongation of a tensile specimen for the material tested is shown by figure 3. It can be seen from these curves that the presence of a hole greatly decreases the over-all elongation of the member at failure. The ratio of the elongation of a 1/4-inch perforated specimen to that for a 1/4-inch solid specimen over gage lengths from 0.2 inch to 2 inches is plotted in figure 4. The curves of figure 4 indicate that, contrary to the relation for the reduction in strength, the reduction in elongation is greater for the hard-rolled material than the annealed material. In the case of AM-C52S-H, the elongation measured over 2 inches of the perforated specimen was only about 2 percent of the value for a solid specimen while for AM-C52S-O it was about 3.5 percent of the value for a solid specimen. Figure 5 illustrates the elongations over varying gage lengths for the material tested, as it is affected by the ratio of hole diameter to sheet width. It is seen that an increase in d/b ratio results in a decrease in percent elongation in all cases. This is reasonable to expect since for the narrow specimens the ratio of net to gross area will be smaller than for the wide specimens.

Specimens Containing Two Staggered Holes

The specimens included in series II of table I contain two holes, each located with the same eccentricity on opposite sides of the longitudinal center line and with varying pitch (spacing in the direction of stress).

The results of the tests on this series of specimens are summarized in table V. For AM-C52S-H, when the pitch became equal to the eccentricity (type 25), the fracture did not occur on the net section corresponding to that for which the net area was calculated. Calculations of the least net section indicated that the least net width would follow a staggered pattern. Failure, however, was straight across the specimen through one hole. Alloy AM-C52S-O did not react in the same manner, all failures occurring through the calculated least net section.

The efficiency values for the specimens of this type are plotted in figure 6 against the ratio of pitch to gage $s/2e$, where e is the spacing between a hole and the center line. The nature of the failure is also indicated in this figure. These curves indicate in general that, for a given gage, the efficiency decreases with increase in pitch as long as the least net width results in a staggered line. For failures that occur straight across, however, the ratio of pitch to gage has little effect on the efficiency. As was the case for the single-hole specimens, greater reductions in strength are exhibited by the annealed material than the hard-rolled material. The efficiency of this type of specimen is considerably lower than that of a specimen with a single central hole. This is accounted for by the fact that when staggered holes are present bending stresses are introduced because of the eccentricity of the holes. The lowest efficiency, based on the least net width, occurred with a pitch-to-gage ratio of 2 (type 27), the average values being 74 percent for AM-C52S-O and 79 percent for AM-C52S-H.

Specimens with Four-Hole Pattern

The specimens listed under series III of table I contain four holes arranged in a symmetrical pattern. All specimens were of the same width and the holes had a constant gage. As with the staggered two-hole pattern, the variable studied was the pitch of the holes. Results of the tests on specimens in this group are summarized in table VI and the efficiencies of the different types of specimens are plotted in figure 7 against the ratio of pitch to gage. These curves illustrate that for a fracture occurring on a staggered line the efficiency decreases for an increase in pitch while, for specimens which fracture straight across, the efficiency is increasing at a ratio of pitch to gage of 2, the limiting ratio tested. Consistent with the other two patterns tested the annealed material again indicates greater reductions in strength than the hard-rolled material.

For this group of specimens, the lowest efficiencies, based on the least net width, occurred with specimens of type 37 which has a pitch-to-gage ratio of 1. Average values were 84 percent for AM-C52S-O and 93 percent for AM-C52S-H. The efficiency values obtained on specimens in this group were higher than those for the two-hole staggered pattern and suggest higher efficiencies if the two-hole staggered pattern were repeated in wide specimens. This has been shown to be the case by a previous supplementary investigation (reference 10) where the two-hole pattern repeated in a wide specimen indicated a reduction of strength of not over 5 percent as compared with corresponding reductions of almost 20 percent in narrower specimens containing a single two-hole staggered pattern.

SUMMARY OF RESULTS

The results of tests to determine the relative effect of various patterns of open circular holes, covering a range of d/b (ratio of hole diameter to total width) values and hole spacings, on the tensile strength and elongation of AM-C52S-O and AM-C52S-H magnesium-alloy-sheet specimens may be summarized as follows:

1. Mechanical properties of the materials used were in good agreement with the typical values given for the materials.

Specimens with single central hole:

2. The hole produced a reduction in the ultimate tensile stress based on the net section of the specimen, the reduction being greater for the annealed material.

3. The reduction in strength for AM-C52S-O varied with the ratio of hole diameter to width of sheet, amounting to about 19 percent at a d/b ratio equal to 0.1 and about 8 percent for d/b ratios of 0.2 and 0.4.

4. For AM-C52S-H the reduction in strength was independent of d/b ratios (between 0.1 and 0.4) and did not exceed 5 percent.

5. The elongation values for the perforated specimens were greatly reduced over those for solid specimens of the same width. The reduction was greatest for the narrowest specimen and for the hard-rolled material. For a ratio of d/b equal to 0.4 the reduction in elongation in a 2-inch gage length was about 98 percent for AM-C52S-H and 96.5 percent for AM-C52S-O. On a 0.2-inch gage length, the reduction in elongation was about 91 percent for AM-C52S-H and 82 percent for AM-C52S-O.

6. The single-hole pattern repeated in a wide specimen probably will result in smaller reductions in strength than for the single-hole specimens tested.

Specimens containing two staggered holes:

7. The holes produced a reduction in ultimate tensile strength on the net section which increased with an increasing ratio of pitch to gage, to a ratio value of 1, beyond which the reduction was practically constant.

8. The reduction in strength was greatest for AM-C52S-O, the maximum reduction being about 26 percent.

9. The maximum reduction in strength for AM-C52S-H was about 21 percent.

10. This pattern repeated in a wide specimen will probably result in less reduction in strength occurring. The results of a previous supplementary investigation showed that when the staggered two-hole pattern was repeated in a wide specimen the reduction in strength was only about 5 percent while for narrower specimens containing only two holes in a staggered pattern reductions of almost 20 percent were produced.

Specimens with four-hole pattern:

11. For the specimens containing four holes in a symmetrical diamond pattern in which the pitch of the holes was varied, the reduction in strength increased with increasing ratio of pitch to gage to a ratio value of about 1 and then decreased.

12. The reduction in strength was greatest for AM-C52S-O, the maximum reduction in strength being about 16 percent.

13. The maximum reduction in strength for AM-C52S-H was about 7 percent.

General:

14. Greater reductions in strength were exhibited by the annealed material (AM-C52S-O) than the hard-rolled material (AM-C52S-H).

15. No common index is evident by which to predict the effect of the perforation on the amount of strength reduction.

16. In certain special arrangements of holes such as a single central hole or two holes in a staggered pattern, the resulting reduction in strength may be on the order of 20 percent for the single central hole and 25 percent for the two staggered holes. However, conditions which more nearly represent those commonly met in practice would have this pattern repeated and the reductions in strength would not be so great.

17. The reductions in elongation caused by open circular holes in sheet specimens, contrary to the relation for reductions in strength, are greater for AM-C52S-H than AM-C52S-O.

18. The behavior of the magnesium-base alloy is in general like that of the previously investigated aluminum-base alloys, except for the 1-inch-wide, single-hole specimen of the annealed material, which exhibited a reduction in strength of about 19 percent, compared with a maximum reduction of about 11 percent for any of the aluminum alloys tested.

Aluminum Research Laboratories
Aluminum Company of America
New Kensington, Pa., June 29, 1949

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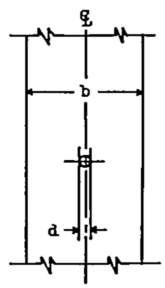
TABLE I

NOMINAL DIMENSIONS OF PERFORATED SPECIMENS

[t = 0.032 in. (20 gage); d = 0.0960 in. (no. 41 drill); d/t = 3]

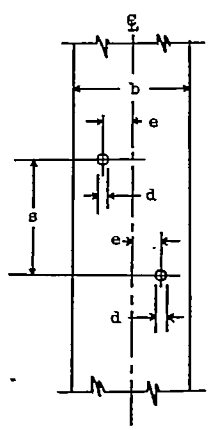
Series I



Type	b (in.)	d/b
1	0.960	0.10
2	.480	.20
3	.240	.40

Series II

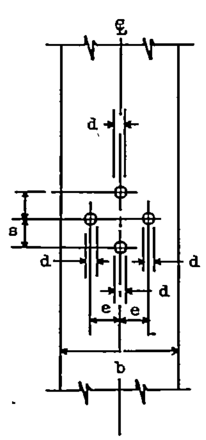
$\left(b = 0.960 \text{ in.}; \; e = 0.360 \text{ in.}; \; e/d = 3\frac{3}{4}\right)$



Type	s	s/e
23	0	0
25	.360	1
26	.720	2
27	1.440	4

Series III

$\left(b = 0.960 \text{ in.}; \; e = 0.240 \text{ in.}; \; e/d = 2\frac{1}{2}\right)$



Type	s	s/e
35	0	0
36	.120	1/2
37	.240	1
38	.480	2

TABLE II

MEASURED DIMENSIONS OF PERFORATED SPECIMENS

Specimen type	Dimension measured (1)	Average measurement (in.) (2)	
		AM-C52S-O	AM-C52S-H
1	b	0.9470	0.9458
	t	.0351	.0333
	d	.096	.096
2	b	.4750	.4720
	t	.0350	.0333
	d	.096	.096
3	b	.2338	.2355
	t	.0350	.0333
	d	.096	.096
23	b	.9462	.9472
	t	.0350	.0333
	d	.096	.096
25	b	.9483	.9490
	t	.0351	.0333
	d	.096	.096
26	b	.9487	.9490
	t	.0350	.0333
	d	.097	.096
27	b	.9493	.9500
	t	.0350	.0333
	d	.096	.096
35	b	.9580	.9577
	t	.0351	.0333
	d	.096	.096
36	b	.9578	.9577
	t	.0350	.0333
	d	.096	.096
37	b	.9580	.9602
	t	.0350	.0333
	d	.096	.096
38	b	.9570	.9553
	t	.0350	.0333
	d	.096	.096

[1]b, width of specimen; t, thickness of specimen; d, hole diameter.

[2]Average of triplicate specimens for each type of specimen except for type 1, 2, and 3 where A specimens have not been included.

TABLE III

TENSILE PROPERTIES OF MATERIALS USED IN TESTS

Alloy and temper	Mechanical properties (1)				Typical mechanical properties (2)		
	Tensile strength		Average yield[3] strength (psi)	Average elongation in 2 in. (percent)	Tensile strength (psi)	Yield[3] strength (psi)	Elongation in 2 in. (percent)
	Average (psi)	Maximum variation from average (percent)					
AM-C52S-O	37,260	1.5	24,600	20	38,000	25,000	18
AM-C52S-H	46,110	1.4	34,700	12	46,000	34,000	10

[1]Determined from standard tensile specimens. All properties cross grain.
[2]Values taken from reference 3.
[3]Stress at 0.2-percent offset.

TABLE IV

RESULTS OF TESTS ON SPECIMENS WITH SINGLE CENTRAL HOLE

[Series I]

Type of specimen (a)	(d/b) (b)	Specimen	AM-C52S-0 Ultimate load (lb)	AM-C52S-0 Efficiency (percent) (c)	AM-C52S-H Ultimate load (lb)	AM-C52S-H Efficiency (percent) (c)
1	0.1	A	[d]924	[d]83	[d]1272	[d]98
		B	915	82	1235	95
		C	890	80	1250	96
		Av.	903	81	1243	96
2	.2	A	[d]463	[d]94	[d]566	[d]98
		B	447	90	557	96
		C	462	93	550	96
		Av.	455	92	554	96
3	.4	A	[d]187	[d]104	[d]210	[d]100
		B	170	94	204	96
		C	162	90	200	93
		Av.	166	92	202	95

[a]See table I for description of specimens.
[b]Ratio of hole diameter to width of specimen.
[c]Efficiency $= \dfrac{\text{Tensile strength based on net area}}{\text{Tensile strength of material}} \times 100.$
[d]Not included in average.

TABLE V

RESULTS OF TESTS ON SPECIMENS WITH TWO STAGGERED HOLES

[Series II]

Type of specimen (a)	$\left(\frac{s}{2e} = \frac{s}{g}\right)$ (b)	Specimen	AM-C52S-O		AM-C52S-H	
			Ultimate load (lb)	Efficiency (percent) (c)	Ultimate load (lb)	Efficiency (percent) (c)
23	0	A	795	81	1150	91
		B	840	85	1127	97
		C	828	84	1115	96
		Av.	821	83	1131	97
25	.5	A	789	76	1065	86 [d]81
		B	803	77	1075	87 [d]82
		C	816	78	1050	85 [d]80
		Av.	803	77	1063	86 [d]80
26	1	A	835	75	1030	79
		B	845	76	1030	79
		C	842	76	1036	79
		Av.	841	76	1032	79
27	2	A	800	72	1037	79
		B	811	73	1006	77
		C	852	76	1060	81
		Av.	821	74	1034	79

[a]See table I for description of specimens.
[b]Ratio of pitch to gage.
[c]$\text{Efficiency} = \frac{\text{Tensile strength based on net area}}{\text{Tensile strength of material}} \times 100.$
[d]Based on area of fracture.

TABLE VI

RESULTS OF TESTS ON SPECIMENS WITH FOUR HOLES

[Series III]

Type of specimen (1)	$\left(\frac{s}{e} - \frac{s}{g}\right)$ (2)	Specimen	AM-C52S-O		AM-C52S-H	
			Ultimate load (lb)	Efficiency (percent) (3)	Ultimate load (lb)	Efficiency (percent) (3)
35	0	A	842	96	1040	102
		B	816	93	1020	99
		C	858	99	1012	99
		Av.	839	96	1024	100
36	.5	A	751	82	1032	96
		B	787	86	1008	94
		C	787	86	1015	95
		Av.	775	85	1018	95
37	1	A	834	83	1095	93
		B	853	86	1097	93
		C	834	83	1095	92
		Av.	840	84	1096	93
38	2	A	883	88	1170	100
		B	886	89	1193	102
		C	877	88	1150	98
		Av.	882	88	1171	100

[1]See table I for description of specimens.

[2]Ratio of pitch to gage.

[3]Efficiency = $\frac{\text{Tensile strength based on net area}}{\text{Tensile strength of material}} \times 100$.

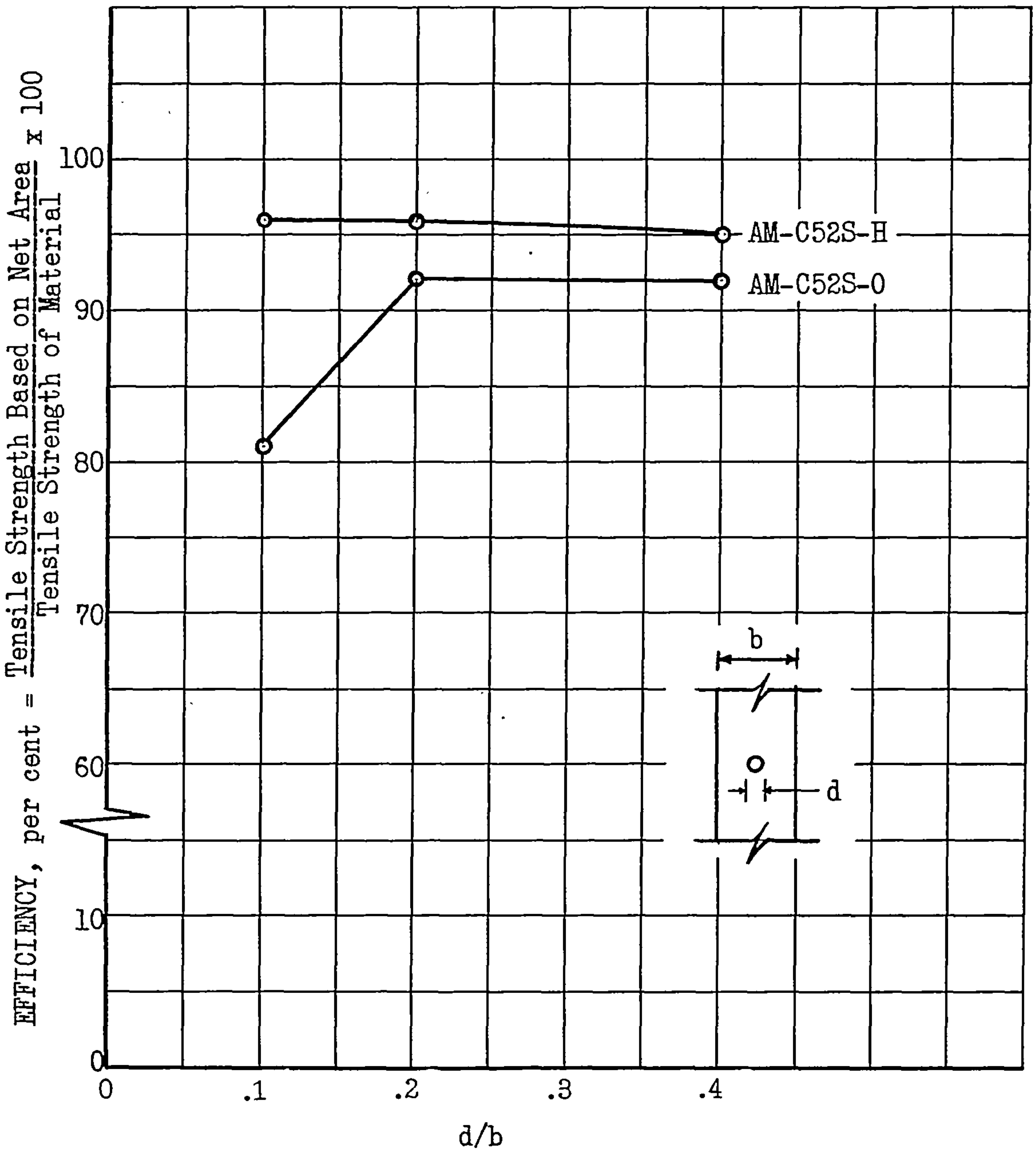


Figure 1.- Effect of central circular hole on tensile strength of AM-C52S-O and AM-C52S-H magnesium alloys.

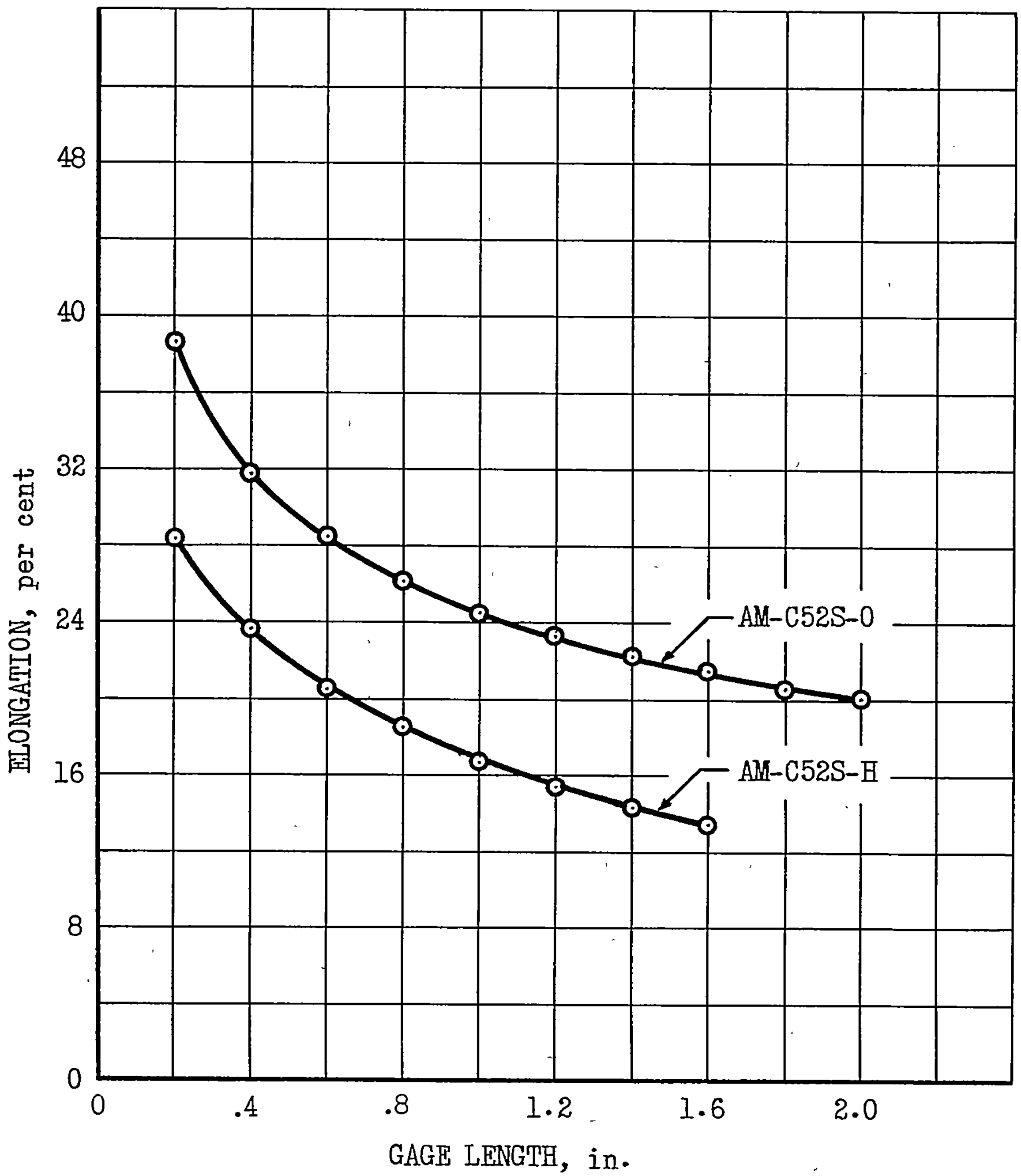
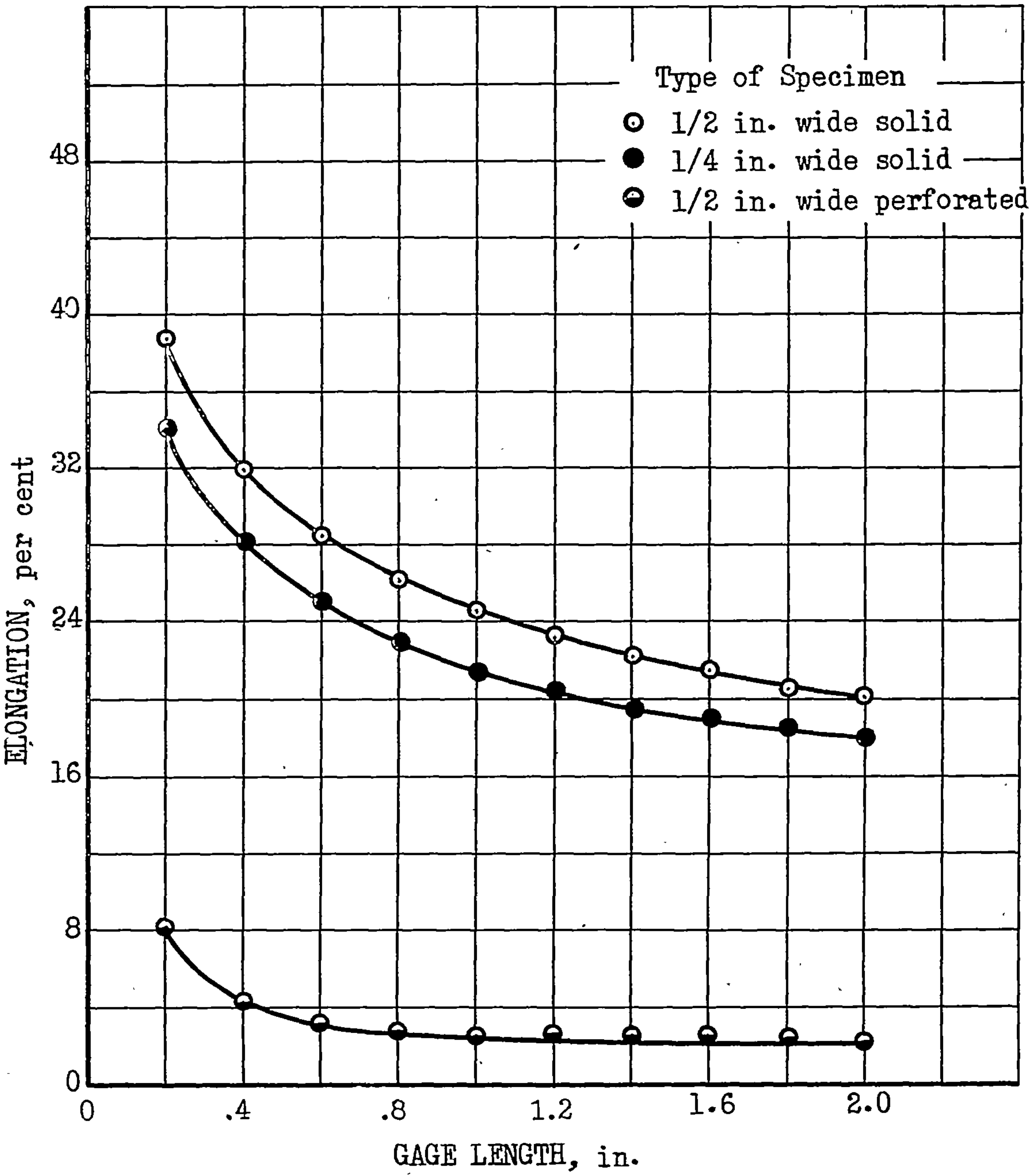
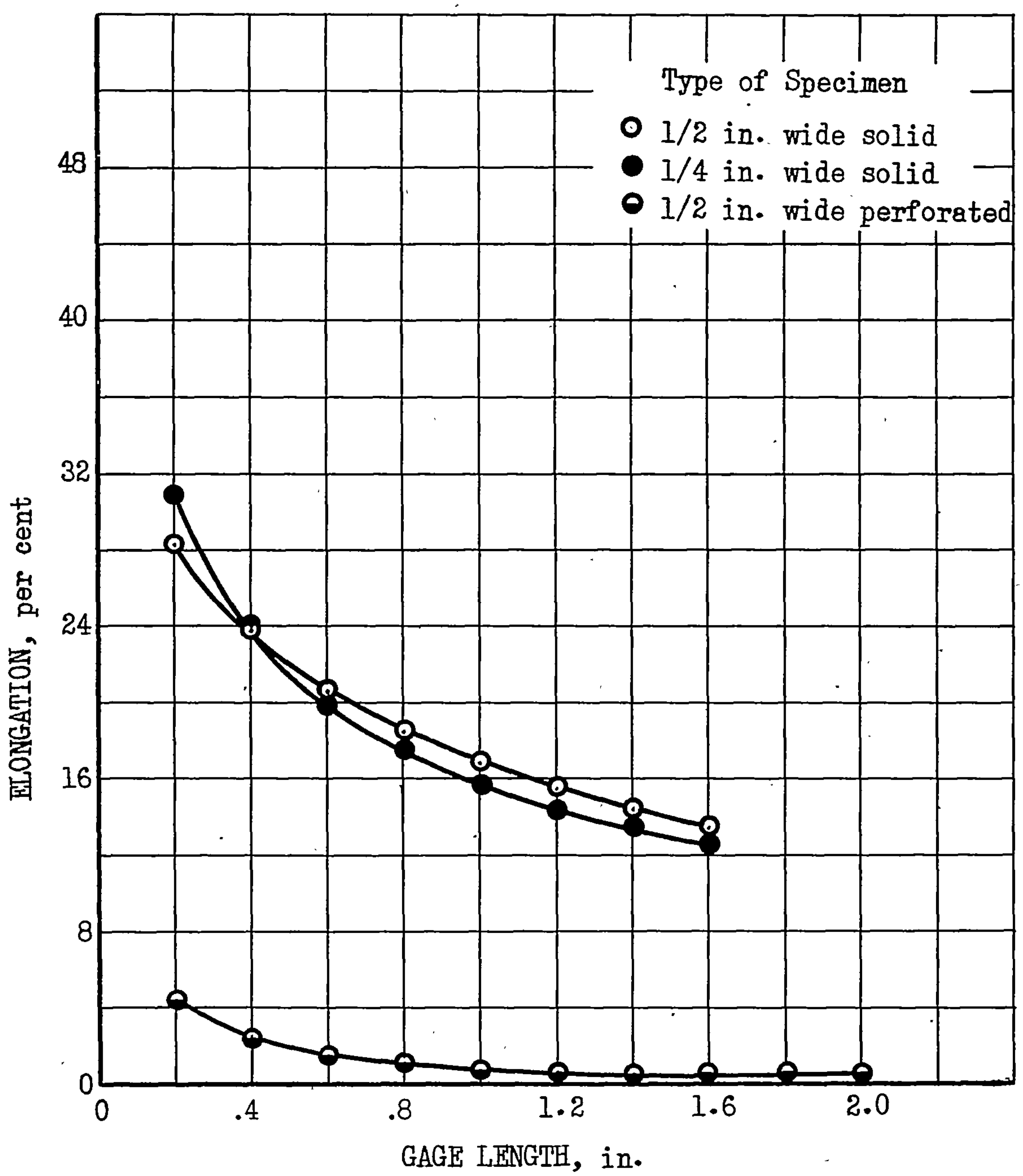


Figure 2.- Variation of elongation with gage length. Solid specimen 1/2 inch wide. AM-C52S-O and AM-C52S-H magnesium alloys.



(a) AM-C52S-O magnesium alloy.

Figure 3.- Variation of elongation with gage length. Solid and perforated specimens.



(b) AM-C52S-H magnesium alloy.

Figure 3.- Concluded.

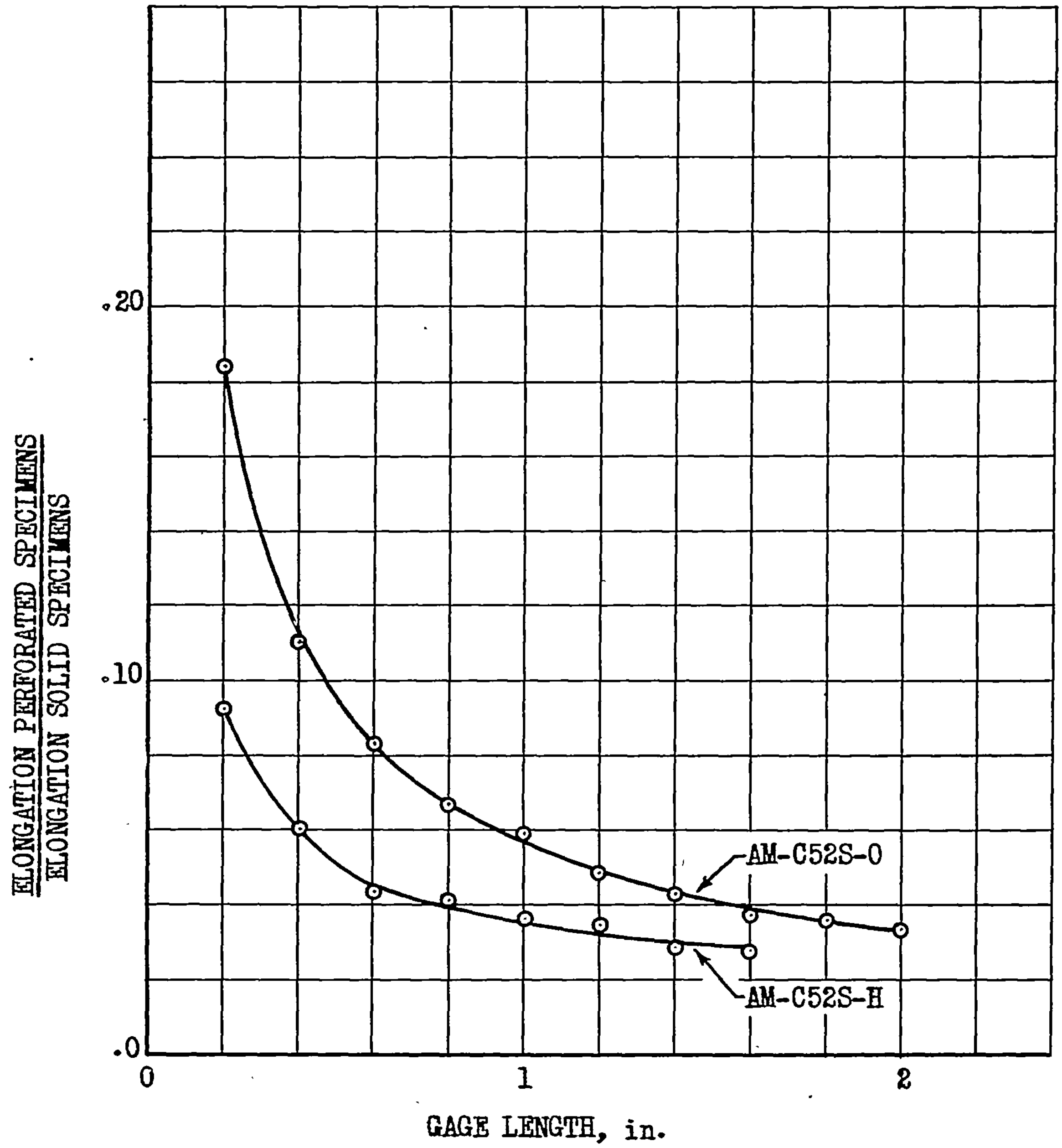
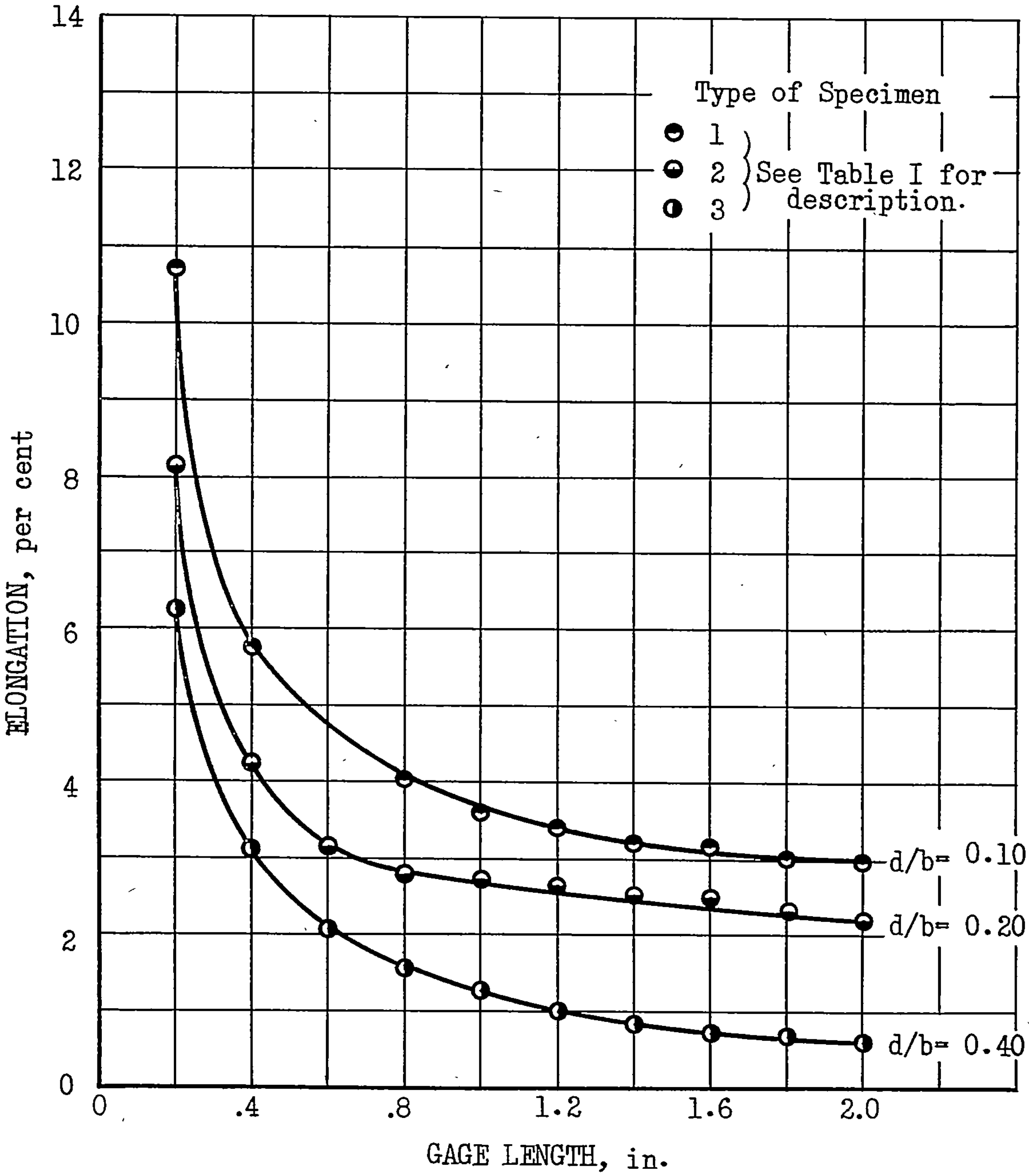
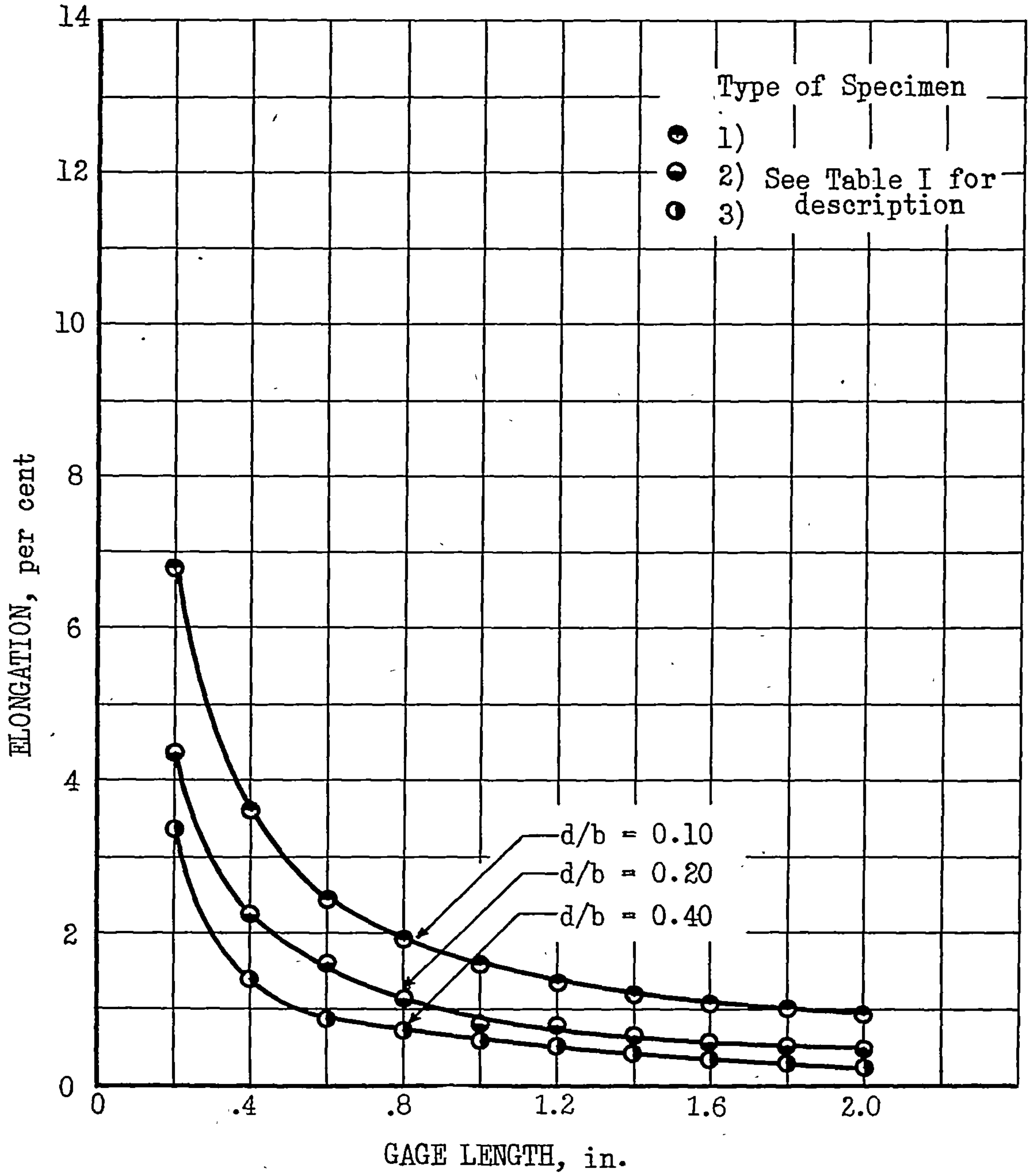


Figure 4.- Ratio of elongation of 1/4-inch perforated to 1/4-inch solid specimens against gage length for AM-C52S-O and AM-C52S-H magnesium alloys.



(a) AM-C52S-0 magnesium alloy.

Figure 5.- Variation of elongation with gage length for various d/b ratios.



(b) AM-C52S-H magnesium alloy.

Figure 5.- Concluded.

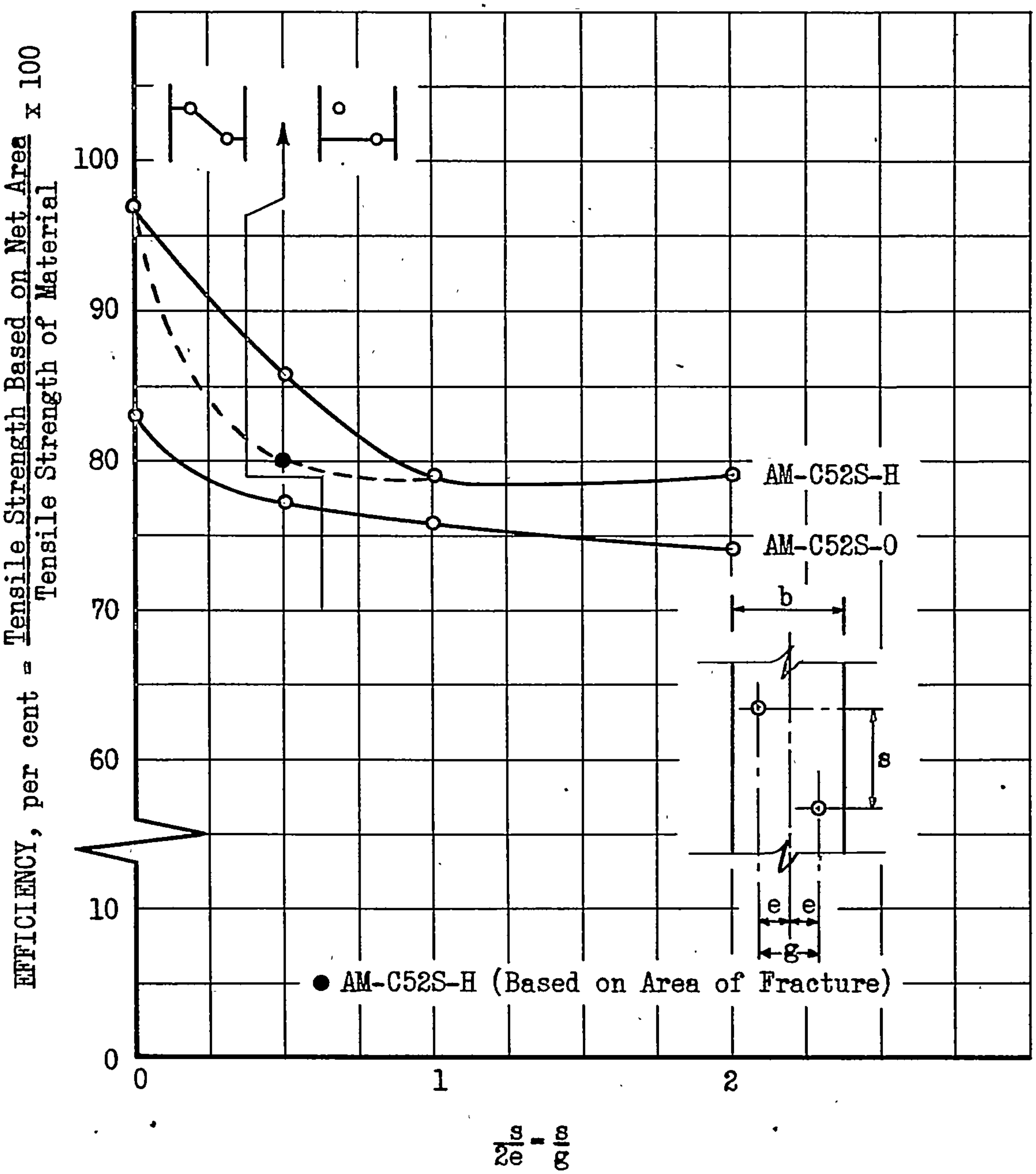


Figure 6.- Effect of two staggered holes on tensile strength of AM-C52S-0 and AM-C52S-H magnesium alloys.

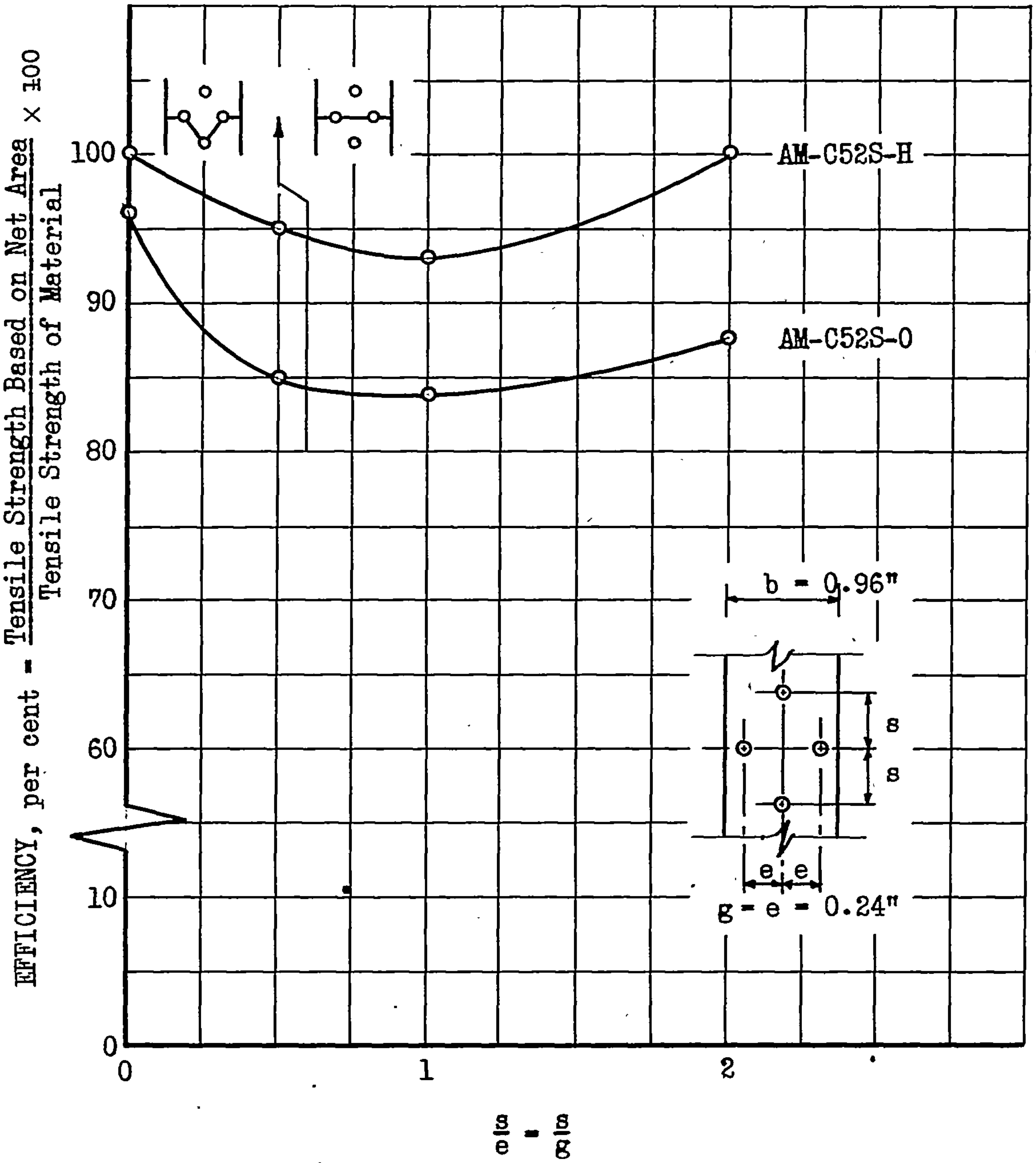


Figure 7.- Effect of four-hole pattern on tensile strength of AM-C52S-0 and AM-C52S-H magnesium alloys.